A REVIEW OF AQUACULTURE IN HAWAII AND ITS POTENTIAL ENVIRONMENTAL IMPACTS

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science

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ABSTRACT

Hawaii has a long history of aquaculture. Before Europeans arrived in the Hawaiian Islands, Hawaiian people already had advanced forms of aquaculture with the use of fish ponds. These fish ponds were a symbol of power and society for the Hawaiian people. In modern Hawaii, fish ponds have been supplemented to some extent by industrial methods develop since the 1960s. These advancements have led to new technologies such as sea cage aquaculture of economically important carnivorous fin fish. The ecological impacts of these new technologies are potentially dangerous. Negative environmental impacts from aquaculture could damage the Hawaiian economy which relies on a healthy ocean for tourism and fisheries. A return to pre-contact principles of aquaculture could eliminate environmental impacts as well as imports needed by modern aquaculture. This could lead to a more sustainable form of food production for the Hawaiian Islands.

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Chapter 1 Introduction

The Hawaiian Islands have a long history of aquaculture starting with the fish ponds created by the Hawaiian people before western contact. Early aquaculture involved a variety of different systems which made aquaculture feasible in all of the main Hawaiian Islands. Today aquaculture is growing rapidly with many new technologies such as open ocean sea cages. Pressure for increased fish farm production in Hawaii has been attributed to population increases in the islands, and the declining wild fishery, as well as government incentives and research programs. Increases in transportation costs and the cachet of locally produced food have attracted investors to aquaculture in Hawaii. This thesis reviews the history of Hawaiian aquaculture and its evolution to modern times, as well as evaluates the environmental impacts of modern aquaculture, and suggests potential guidelines for sustainable aquaculture development for Hawaii.

Chapter 2 History of Aquaculture in Hawaii

Ancient Hawaiian Aquaculture

A relatively advanced system of aquaculture in the islands was established before the first Europeans arrived (Cleghorn et al. 1990). Fish ponds in Hawaii were manmade enclosures in which fish were grown until harvest (Cleghorn et al. 1990). The use of fish ponds was wide spread throughout all inhabited islands in the archipelago. These fish ponds, of which many are still in use, have important economical and historical value

(Cleghorn et al. 1990). In the past 20 years, there have been many efforts to restore these fish ponds to their previous functioning state. A Department of Land and Natural Resources survey identified 488 fish ponds in the state (Cleghorn et al. 1990). These fish ponds can be classified into six groups (Figure 1).

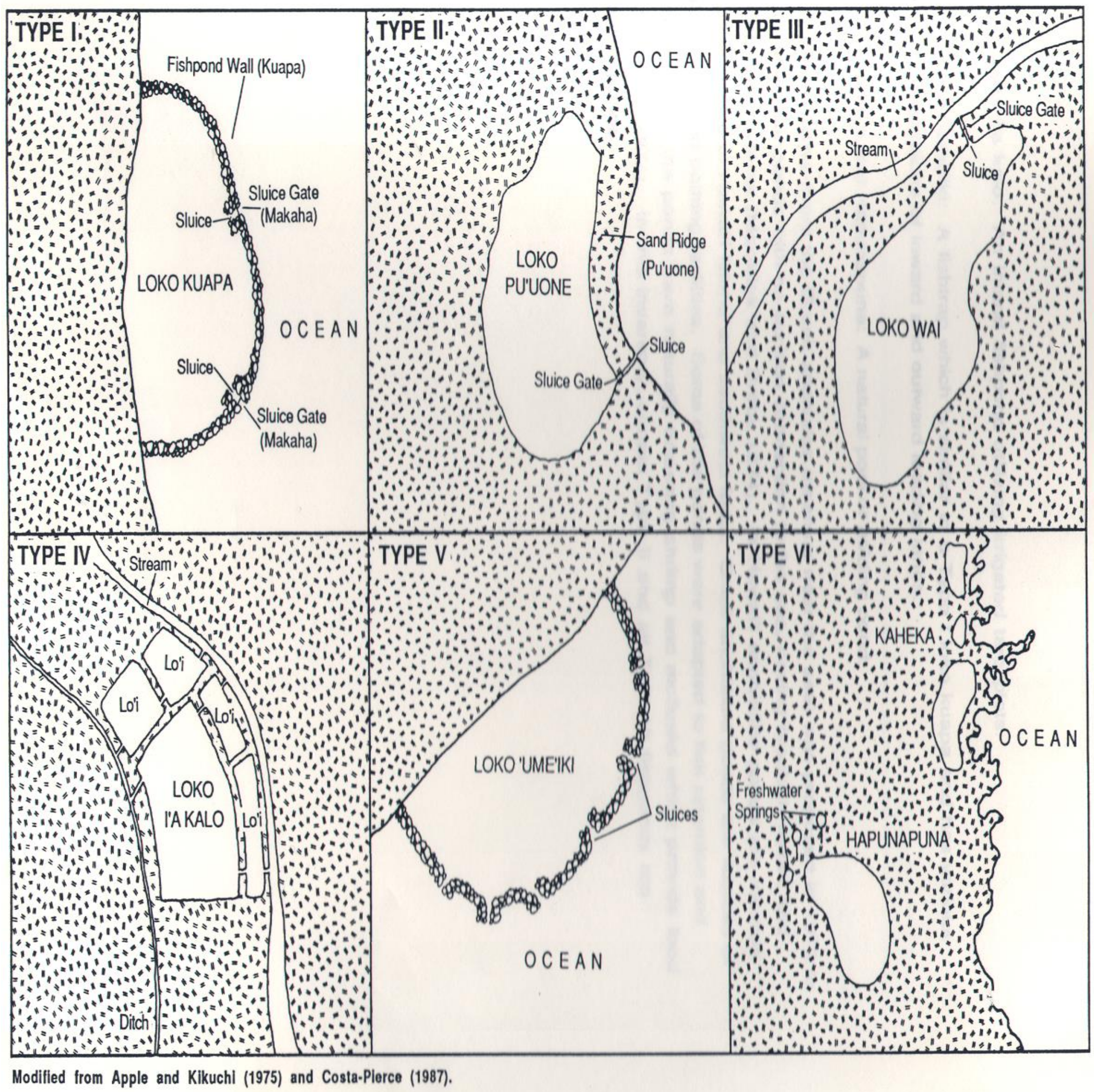

Figure 1 Main types of Hawaiian Fish Pond (Cleghorn et al. 1990)

The first group, Loko Kuapa, contains marine ponds with land on one side with the other three sides constructed of coral or stone walls separating the fish pond from the ocean. These fish ponds are located in marine environments. Openings in the coral or stone walls, called makaha, which control the flux of water from the outside ocean. Fluxes of ocean provide a source of nutrients and biota. Loko Pu’uone are marine fish ponds that are surrounded by the shore on three sides with a small sandbar barrier separating the pond from the ocean. Fluxes of ocean water are controlled by a small channel with a gate or sluice. Loko Wai are inland freshwater ponds, usually formed from a natural lake or swamp. Inputs of fresh water come through a sluice connected to a freshwater stream. Aquaculture and agriculture are integrated at one location through the use of a Loko i'a Kalo fish pond setup. Such fish ponds are connected to a taro patch called a lo'i. Loko 'Ume'iki fish ponds are another type of marine fish pond which is very similar to the Loko Kuapa fish pond, but they have many breaks in the coral or stone wall giving entry to fish at high tides while preventing escape at low tide. Kaheka and Hapunapuna are natural pools used for holding fish but are not set up as self sustaining ecosystems (Cleghorn et al. 1990).

The frequency of fish pond types varies between islands (Figure 2). On Oahu the majority of fish ponds are Loko Wai followed closely by Loko Kuapa. Oahu has more fish ponds than any other island in the state. On the island of Molokai, Loko Kuapa dominates. On the islands of Hawaii, Maui, and Kauai, the Loko Pu'uone is the most abundant (Cleghorn et al. 1990).

Historically, marine fish ponds were controlled by the royalty, or ali’i. Their ponds were watched by people called konohiki who maintained the ponds while protecting them from theft.

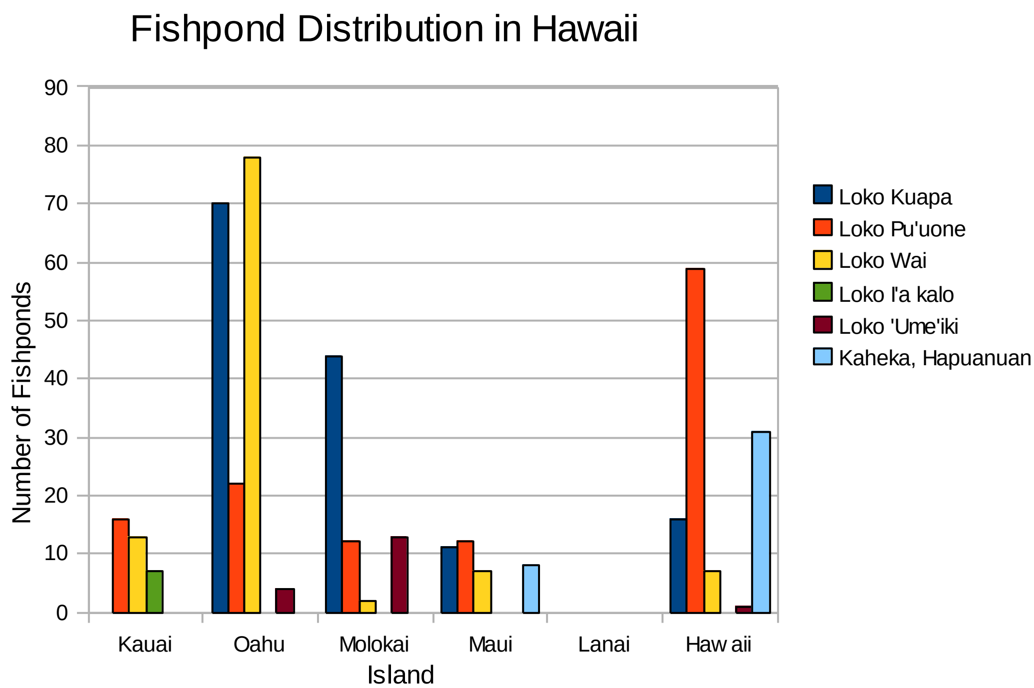

Figure 2 Fish Pond Distribution in Hawaii

From Costa Pierce 1987

The common farmers and fishermen maintained fresh water ponds for themselves, such as the Loko Wai. As people placed fresh caught fish in taro patches (lo'i) to preserve freshness, they discovered that mullet actually thrived in the lo'i. Mullet helped clean the taro patch by grazing, eliminating excess debris (Handy et al. 1972). Some fish ponds were built on naturally occurring freshwater springs (Ualapu'e Moloka'i 1991). These springs were thought to be connected to an underground network of tunnels. Some tunnel systems were very large, and one such system was thought to flow beneath the Koolau mountain range on Oahu (Handy et al. 1972). The evidence was the disappearance of large schools of mullet from one fish pond followed by the appearance in another fish pond on the other end of the island some time later (Handy et al. 1972).

In addition to containing the fish that were farmed, the marine fish ponds contained many other naturally occurring forms of aquatic life. Shrimp, mollusk and seaweed were abundant in these fish ponds and were used as feed and baits (Cleghorn et al. 1990). Nutrient and biological flux from the open ocean was assured by the incoming tide. The tidal fluxes were of great importance to the operators of the fish ponds. During the na la au, days of high tides during a full moon phase, larger fish from the outside entered into the fish ponds. When the tide was full, the gates or makahas would be shut preventing the fish inside the pond from escaping (Handy et al. 1972). Also, the tides were utilized in harvesting the fish. When the tide began to ebb, the makaha would be used as traps to catch larger fish that were trying to escape. Inland fish ponds such as Loko Pu'uone were under less influence from the tides and therefore not as productive in catching fish that normally lived outside the fish pond. Using the makaha to harvest fish was only an option during very large tides (Ualapu'e Moloka'i 1991).

The most common fish in marine fish ponds were mullet *Mugil cephalus* or Ama' Ama', milkfish *Chanos chanos* or awa, and various types of shrimp, guppies and eels. These fish were not reserved for the ali'i and could be eaten by the common people. During high tide events, a number of different species would enter the fish ponds, possibly in search of food. These fish include giant trevally *Caranx ignobilis* or ulua, amberjack *Seriola dumerili* or kahala, goat fish *Mulloidchithys vanicolensis* or weke, surgeon fish *Acathruus dussumieri* or palani, and parrot fish *Chlorurus sordidus* or uhu (Handy et al. 1972). Because these fish only entered at certain times, their entry was believed to be the work of the kahunas (religious leaders). Such fish were generally reserved for royalty(Handy et al. 1972). Barracuda *Sphyraena barracuda* or kaku resided in both marine and brackish fish ponds. They fed primarily on mullet (Ualapu'e Moloka'i 1991). The barracuda was a natural predator that ate weak or sick mullet, thus helping to keep the fish stocks healthy.

The decline of fish ponds in Hawaii can be attributed to various changes that resulted after European contact. One of the major reasons for their decline was the emergence of the sandalwood trade. Many of the people responsible for fish pond maintenance were ordered into the forest by the chiefs to cut down trees (Farber 1997). Also the decrease in population, resulting from the introduction of disease, meant fewer workers to operate the fish ponds. By the time Hawaii became a territory of the United States, only 100 of the 488 fish ponds were still in use, producing only one third the fish of pre-European contact time (Farber 1997). By the 1970s, fish pond annual production was less than 10,000 kg or about one percent of pre-European contact production (Tamaru 1998).

Restoration of these degraded fish ponds has become a major legal issue. Since the Mahele of 1848 when property of the ali'i was converted into privately owned land, ownership of the fish ponds has become confused. Many developers and coastal land owners find fish ponds limiting their profits. Also private fish pond owners are often subjected to federal and state laws which make restoration difficult due to environmental regulations (Farber 1997). A State of Hawaii Department of Land and Natural Resources Hawaiian Fish Pond Study (Hlawati, 2002), (Cleghorn et al. 1990) recommended revisions to state policy to ease restrictions on fish pond restoration. Hawaii Revised Statutes Chapter 343 which required an environmental impact statement for fish pond restoration (Cleghorn et al. 1990) was revised under section 183B-2 to allow exemptions for fishpond restoration.(Hawaii Revised Statues Chapter 183C, http://luc.state.hi.us/docs/hrs_183c.pdf) Currently, the state of Hawaii owns 28 Loko Kuapa and 38 Loko Pu'uone fish ponds (Cleghorn et al. 1990). These fish ponds may be leased but only within strict guidelines.

Modern Techniques

Modern Aquaculture in Hawaii emerged around 1960. This was due to increased state and federal funding as well as private investors (Corbin 1976). In 1976, there were four organizations conducting aquaculture research in the State of Hawaii: Department of Land and Natural Resources (DLNR), Hawaii Institute of Marine Biology of the University of Hawaii (HIMB), The College of Tropical Agriculture of the University of Hawaii (CTAHR), and The Oceanic Institute (OI), a non-profit private research group. About half the funding came from NOAA Sea Grant (Corbin 1976).

Research in the late 1970s included experiments with a variety of freshwater and brackish water species. These species were tested for viability in the Hawaiian aquaculture market. Three separate research groups tested a variety of different species. Carp and catfish were the least successful in DLNR experiments with only initial research stages completed, but prawn research was extremely successful. HIMB concentrated its effort on Pacific threadfin *Polydactylus sexfilis* or Moi and topminnows, with the topminnow achieving the most success, although the moi was almost as successful (Corbin 1976). The Oceanic Institute developed mullet rearing techniques while milkfish and reef fish research were not as successful. Success was determined by the progress of research completed for each organism. The lowest level of success was selecting the species for research while the highest level of success was achieving acceptable results with the last step minimizing operation cost (Corbin 1976).

The progress of the research was based in five major areas. The most important area of concern was the fish's ability to spawn in captivity. Moi, topminnows, and prawns all spawned in artificial enclosures without any outside influence (Corbin 1976). The next area of concern was the survivability of juveniles. It was found that moi and mullet sometimes had poor survival and growth rates (Corbin 1976). A third important area of concern was nutrition and food requirement. Problems in fin fish arose because the goal of providing an inexpensive, high-quality diet which gave rapid growth could not be reached. The final 2 areas of research focus were marketing and production economics and disease and pathogen controls. The latter was considered the least important area of concern for research development (Corbin 1976).

Prior to the 1970s, commercial aquaculture was limited to a handful of individuals maintaining old Hawaiian fish ponds. In the 1970s, federal and state funding increased dramatically for aquaculture research and development. This led to an increase in commercial aquaculture in the islands as compare. As of 1978, there were approximately 16 commercial aquaculture operations in Hawaii (Corbin 1976). These operations could be broken down into two different groups. The first, more abundant, group was the small prawn farms, which were low intensity operations funded by private individuals who usually had no employees. The second group consisted of two companies which had intensive aquaculture operations and hired many full time employees. This included Oahu Oyster Farm, Inc. and Fish Farms Hawaii. These farms produced oysters, catfish, and prawn (Corbin 1976).

In the 1980s, aquaculture in Hawaii was on the increase. Act 236, SLH 1985 established a 23 member advisory council in the DLNR, which was a collection of university and private sector individuals to advise legislation on how to improve the aquaculture industry in Hawaii(DLNR 1989). By the late 1980s many new commercial aquaculture companies were started. In 1987 total aquaculture production valued at about $6.2 million.

At this time, a number of new aquaculture areas were becoming very successful. The Natural Energy Laboratory of Hawaii (NELH) on the island of Hawaii was in an early stage of development, but was expanding rapidly (DLNR 1989). The major companies at NELH at the time were: Cyanotech which controlled 15 acres of ponds; Ocean Farms Hawaii which grew abalone was began experimenting with salmon, oysters and sea urchin; Royal Hawaiian Sea Farms grew sushi grade seaweed (DLNR 1989). There was experimental cultivation of American lobster and hirame flatfish, as well.

Another important fish farm area was the Kahuku Aquaculture Park located on the island of Oahu. This zone of about six farms had semi intensive aquaculture of shrimp in earth ponds as well as intensive aquaculture for tilapia in concrete raceways. Companies located in Kuhuku during 1987 included Amorient Aquafarm, a shrimp producer, Pacific Sea Farms which focused on tilapia and shrimp, Aurea-Marine which grew tilapia, shrimp and seaweed, Hawaiian Marine Enterprise which grew seaweed, The Kahuku Prawn Company which produced freshwater prawns, and Pa Paloko Wai Crump Ranch, a frog farm (DLNR 1989).

Also in 1987 the Hawaiian Ocean Science Technology Park on the Big Island neared completion. This 547 acre facility pumped cold ocean water for both warm and cold water aquaculture. The first tenants would come in 1989 with ideas of raising mahi mahi and salmon (DLNR 1989).

Federal funding was provided in 1987 to expand the Oceanic Institute as well as to start the Center for Applied Aquaculture (CAA). The goal of the CAA was to serve as a national aquaculture research center as well as to help Hawaii to lead the nation in the aquaculture industry (DLNR 1989).

Presently the island of Hawaii has the majority of aquaculture with about 80 percent of value in the state. In 2007 Hawaii's aquaculture sales hit a record $25.3 million mark (Pacific Business News 2008). Algae sales made up 43 percent of the value, at $10.9 million. Fin fish sales totaled $4.5 million; ornamental fish, $2.4 million; and other, such as seed stock, brood stock and so forth, $6.8 million (Pacific Business News 2008).

Many of the techniques of prawn raising in the 1970s and 1980s remain, but some important new and very industrial methods of aquaculture have come in to play since the 1990s. On the island of Hawaii is the Natural Energy Laboratory of Hawaii Authority. This is an 870 acre facility which uses a 7,000 ft. pipeline that pumps waters off Keahole Point (Pacific Business News 2008). The water is removed at a depth of 3,000 feet and pumped into tanks at the facility. Between 6.5 billion to 7 billion gallons of 42 degree Fahrenheit water is pumped annually (Pacific Business News 2008). This supply of cold water allows for the culture of temperate species in a tropical location. Ninety-four percent of the water that is pumped is used by 18 commercial aquaculture companies (Pacific Business News 2008). These companies produce a large variety of productions with many different uses.

The Big Island Abalone Corporation grows Japanese Northern abalone and red abalone for high end Japanese restaurants. Indo-Pacific Sea Farms developed technology for commercial rearing of reef building organisms that are photosynthetic such as scleractinian corals. Kona Bay Marine Resources produces specific pathogen-free shrimp brood stock and also produces certified disease-free bivalve seed. This company was awarded the Governor's Exporter of the Year award for 2004. Kona Cold Lobsters currently does not raise lobsters but imports them from North Atlantic Fisheries. Although Kona Cold Lobsters LTD. acts as holding tanks for distribution, the company’s long term goals include becoming independent of Atlantic fisheries and rearing its own lobsters (NELHA). Ocean Rider, INC. produces seahorses for the aquarium trade. Taylor Shellfish-Kona produces juvenile Manila clams then exports them to company-owned inter tidal areas in the Pacific Northwest. Uwajima Fisheries, Inc produces Japanese Flounder for Hawaii's sashimi and sushi markets. Also Uwajima Fisheries, Inc conducts semi-intensive production of moi (Pacific threadfin) and milkfish. (NELHA)

Another advanced industrial technique adopted in Hawaii is the use of sea cages. This technique is viewed by many in the industry as the future of aquaculture. Sea cages, as the name implies, are large cage-like structures which are moored underwater in the open ocean.

In 1999 the University of Hawaii Sea Grant and the Oceanic Institute partnered to determine the feasibility of offshore aquaculture in Hawaii, The efforts lead to the development of a successful demonstration of offshore culture of tropical marine fish species (NOAA NEWS). Moi, whose brood stock came from the initial research in the 1970s, were used to populate a $90,000 NASA-developed 50 by 80 foot biconical sea cage called the Sea Station 3000(figure 3). This cage was moored about 2 miles offshore Barbers Point, Oahu (NOAA NEWS). In two separate trials 130,000 moi were raised without the use of antibiotics or growth stimulated hormones (NOAA NEWS).

Once the research was a success, the Sea Station 3000 was leased to a commercial company, Cates International, Inc. The first commercial harvest was in January 2002. This 15 year lease allowed Cates International, Inc. to build up to four cages at the site but presently they only have 3. The UH Sea Grant and Oceanic Institute supply Cates International, Inc. with the fry stock (NOAA NEWS).

Kona Blue Water Farms is another industrial commercial aquaculture farm which utilizes sea cage aquaculture. Their 3,000 cubic meter cages are located about half a mile off of the Kona coast of the Island of Hawaii, 200 feet below the ocean's surface (http://www.kona-blue.com/sustainability.php). Kona Blue Water Farms raises sashimi grade almaco jack for high end sushi restaurants. The farm also claims they are sustainable and use no growth hormones, antibiotics or genetic engineering (http://www.kona-blue.com/sustainability.php). Kona Blue Water is expanding rapidly and as of January 2008, they have eight functional cages, but an addition $2.6 million raised from private investors will likely double their numbers (Pacific Business News 2008).

Kona Blue Water Farms and Cates International, Inc. are currently two of the only four sea cage offshore aquaculture farms in the United States (gulfcouncil.org). Hawaii is leading the way with offshore aquaculture and there are presently three other offshore farms applying for permits in Hawaii. Ahi Nui and Ahi Farms are companies with plans to farm big eye and yellow fin tuna. Ahi Nui applied for a site off the Kohala Coast of the island of Hawaii but was rejected due to public opposition (gulfcouncil.org). Ahi Farms has applied for a permit to operate off the west coast of Oahu. These companies plan on getting their stock from small fish caught by local fisherman (gulfcouncil.org). The third company applying for permit, Pacific Ventures, requested to grow almaco jack and moi off the Maui coast. This was denied because the requested location was in the Hawaiian Islands Humpback Whale National Marine Sanctuary.

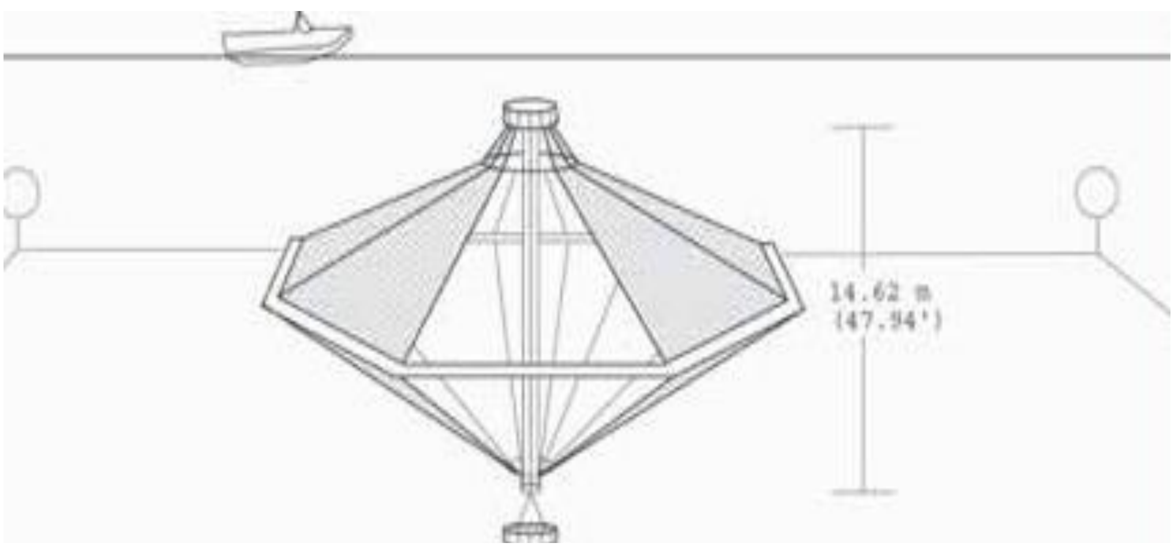

Figure 3 Sea Station 3000[1]

Accessed via website <http://www.oar.noaa.gov/spotlite/archive/spot_hawaii.html>

June 2, 2009

Chapter 3

Modern Aquaculture Systems in Hawaii – Ecological Impacts

Sea Cage Aquaculture

The State of Hawaii is the leading U.S. authority in sea cage aquaculture (gulfcouncil.org). With two farms currently in operation and one more pending, Hawaii accounts for more than half of the United States sea cage aquaculture production. Hawaii is an ideal location for sea cage culture operations, because of the lack of a continental shelf. The presence of pelagic conditions very close to shore, eliminates much of the fear of euthropication that plagues shallow coastal zone operations on continents. Deep water and vigorous ocean currents insure maximum dilution of excess feed and waste material.

Declining fisheries in the Pacific require relief from a growing consumer need for seafood in the world. Sea cage aquaculture operations are often promoted as providing relief for wild fisheries because of high production numbers. Aquaculture research facilities such as the Oceanic Institute on Oahu support sea cage aquaculture operations by developing rearing techniques for Moi and Kahala, the two sea cage cultured species in Hawaii. The greatest advantage of cage systems is low capital cost (Huguenin 1997). They are the cheapest system for rearing fish in coastal areas (Beveridge 1996).

Recent legal barriers have been removed and now ocean areas can be leased for the purpose of sea cage aquaculture. The National Offshore Aquaculture Act of 2007 has made this possible.

> The Act directs the Secretary of Commerce to establish an operational permitting process for the development and operation of offshore aquaculture in the U.S. Exclusive Economic Zone (3 to 200 miles offshore). The Secretary of Commerce is to prepare an environmental analysis for

requirements and is authorized to issue permits. Offshore aquaculture is excluded from the definition of fishing. (CHAPTER 190D State of Hawaii 2008)

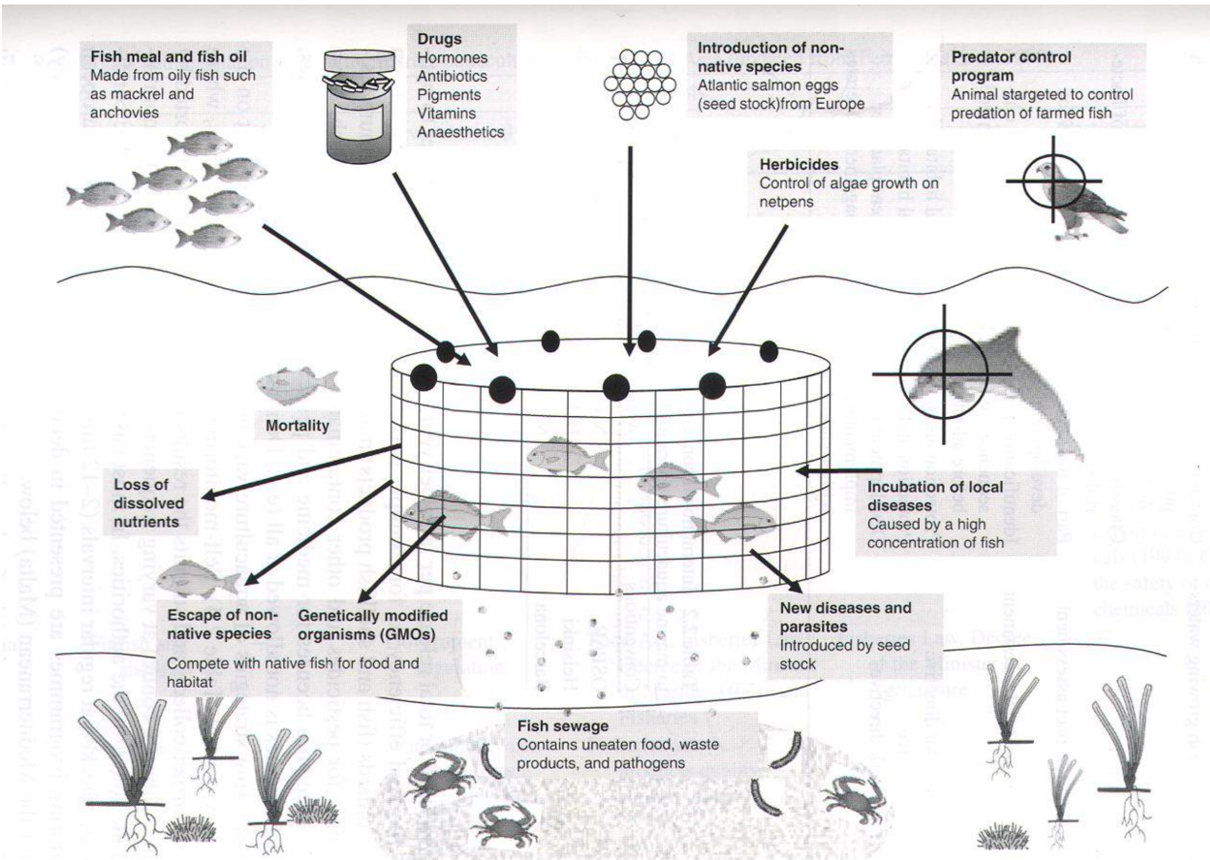

Fig. 2.1 Conceptual figure of aquaculture in the ecosystem (symbols from IAN Symbol Libraries)

Figure 4 Sea Cage Aquaculture and its interactions with natural environment.

From Homer et al. 2008

With the economical benefits of sea cage aquaculture operations it is hard to focus on the negative aspects of sea cage aquaculture (Figure 4). Raising large amounts of predator fish in a cage is not very ecologically sound. There have been examples in the past where sea cage aquaculture has had negative effects on the surrounding ecosystem. The major problem that has plagued these operations is disease. In Canada epidemics of sea lice caused by sea cage aquaculture operations have been responsible for major declines in wild salmon fisheries (Hume 2004).

A sea cage “ecosystem” is a breeding ground for pathogens and parasites. The high volume of waste products from fecal matter as well as excess feed combined with decayed fish promotes a very unclean/unhealthy environment. In addition the open ocean is home to many mobile parasites and pathogens. In overstocked cages fish can sustain physical injuries from abrasion against the steel cage (Beveridge 2002) as well as a tremendous increase in waste and mortality rates. The lack of predators in these artificial ecosystems allow for diseased fish to remain alive for much longer than in the wild, turning them into swimming pathogen factories resulting in a increase of infection in other fish, farmed and wild.

There are many other negative impacts of wild fisheries associated with sea cage aquaculture in addition to disease. Raising carnivorous fish requires a lot of feed. Fishmeal used in feed comes from so called “trash fish” which provide important ecosystem services (Naylor et al. 2000). They provide food for important commercial pelagic fish as well as consume potentially harmful zooplankton and phytoplankton such as diatoms responsible for harmful algae blooms. A lot of fish meal is wasted in large intensive sea cage operations which rely on compressed air or mechanical feeders

(Beveridge 2002). Depleting fish stocks for reduction purposes is likely to have negative impacts on the world's oceans (Naylor et al. 2000).

Another problem associated with sea cage aquaculture is escaped fish. Escaped fish pose a real threat to wild fisheries. Farmed fish are genetically the same, in contrast to wild fish which have high genetic variability. If farmed fish escape from cages and reproduce with wild fish the genetic fitness of the wild population is reduced (McGinnity 2009). Low variability may have detrimental fitness implications (Cross et al. 2008). There is evidence for a positive correlation between variability and fish performance in a wide range of fish species (Cross et al. 2008). Reduction in fish performance results in reduction in survival and productivity. Besides reducing genetic variability escaped fish can interact with wild populations indirectly through ecological competition and disease introduction (Cross et al. 2008). This could reduce the size of wild fishery population which would then reduce genetic drift. Large sea cage operations in the middle of the ocean, especially in the pelagic zone such as those in Hawaii, act as fish aggregation devices (Boyra et al. 2004).They create artificial ecosystems which attracts wild fish due to the structure and the abundance of food. This in turn would modify the diet of the wild fish. Wild fish could also be more easily affected by disease due to their close proximity to these sea cages.

Sea cage aquaculture creates externalities via the impact on the marine environment (Whitmarsh et al. 2008) (Figure 5). Most of these externalities are hard to quantify but can make an economical impact on the people who live in the coastal zone (Whitmarsh et al. 2008). The largest external cost of sea cage aquaculture comes in the form of negative environmental and ecological impacts mentioned in the paragraphs above. Destruction or degradation of a marine ecosystem would hurt fisheries and tourism industries alike. Although sea cage aquaculture capital costs are low for the operator, greater cost may be in store for the coastal residents who rely on the ocean for their livelihood. .

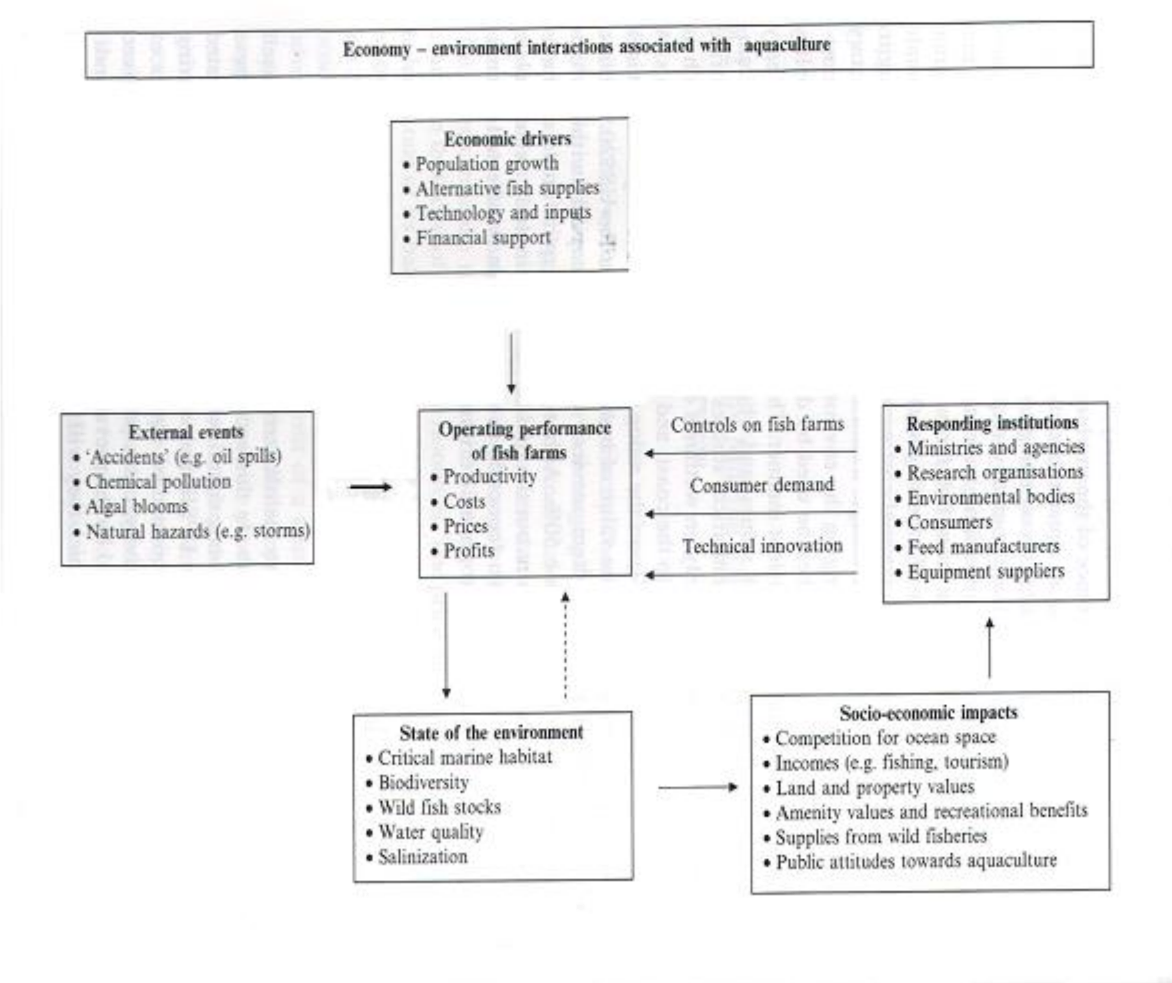

Figure 5 Economy and environment interactions in sea cage aquaculture

(after Whitmarsh et al. 2008)

Potential Negative Impacts of Sea Cage Aquaculture

Drug Use	Escapes	Disease	Eutrophication	External Inputs
Antibiotics released in system as well as served to consumer	Introduction of non-native species	crowding leads to high mortality of cultured fish	Nutrient load from excess feed and fecal matter	Fish meal use leads to over exploitation of reduction fisheries
Growth hormones delivered to wild fish and herbicides to reduce algae growth	Escaped fish interbreeding with wild fish reducing genetic variability	Epidemics in wild fish	Damage to benthic community	

Figure 6 Potential negative impacts of Sea Cage Aquaculture

Land Based Aquaculture Systems

Another method of aquaculture that is presently being used in Hawaii is land based aquaculture (NELHA). This method raises food outside of the natural ecosystem in man-made closed system containers or artificial ponds. This was the first developed method of farming in modern aquaculture. Examples in Hawaii include Kahuku shrimp farming as well products grown at the Natural Energy Laboratory on the Big Island (Hawaii Aquaculture Advisory Council 1987). Land based aquaculture systems do not provide as many ecosystem services as Hawaiian Fish ponds but they are relatively environmentally sound compared to methods of modern aquaculture such as sea cages.

Land based systems have the potential to minimize interactions with the natural ecosystem. This lack of interaction insures external inputs from the aquaculture operation do not contaminate local marine environments. For example, the farmed fish could not escape because they are surrounded by land. Drugs as well as pathogens are also contained in a land based aquaculture system. Waste inputs into natural ecosystems are limited. Farmed fish also benefit from being separated from natural environment. Within a man-made closed system, variability in sunlight, water turbidity and composition are limited, thus helping the fish to stay healthy. Also the exposure to naturally occurring pathogens is greatly reduced (Beveridge 2002).

The current trend in Hawaii is moving from land based aquaculture systems, because land is very limited and expensive, to open ocean aquaculture, in which there is abundant space. This transition from the land to the ocean in modern aquaculture is also a transition of cost in the aquaculture operation. Many costs can now be externalized to the marine ecosystem in a sea cage aquaculture operation as opposed to land based operations where waste must be disposed of (Whitmarsh et al.2008).

Fish Pond Aquaculture for the Future?

In the future, aquaculture in Hawaii may need to reduce its environmental impacts. Due to the limit of fossil fuels, transportation of goods to Hawaii from the US mainland will become more expensive and less feasible. Modern aquaculture techniques rely heavily on imports, such as fishmeal and sea cages. Aquaculture will need to be viewed more as a system for local food production than for a path of monetary gain. The use of Hawaiian fish ponds may be a solution to provide local food while limiting negative environmental impacts.

Ancient Hawaiian fish ponds were a low intensity operation, meaning they did not require major external inputs into the fish pond. Ancient fish ponds relied on the natural ecosystem to feed and maintain the systems. Modern aquaculture relies on many external inputs to regulate its operations. The first major input in a modern industrial aquaculture farm is feed (Naylor et al. 2000). Currently in Hawaii, there are two major carnivorous species farmed, Moi and Kahala. These fish require fishmeal for food. Fishmeal is made from various types of fish which are lower on the trophic level than the fish humans prefer to eat. Clupeid fisheries are exploited in order to make fishmeal for aquaculture feed (Tacon and Metian 2008). This is contrary to what is commonly believed – that aquaculture is saving wild fisheries from over exploitation. More herbivorous fish can be farmed with less impact then carnivorous fish (Figure 7). Unlike modern industrial aquaculture, the food supply within the Hawaiian fish pond was almost solely dependent upon the physical features of the pond itself (Costa Pierce 1987). Hawaiian fish ponds raised mainly herbivorous fish. These fish such as Ama' ama and Ahole lived off the detritus and plant matter naturally occurring in the fish pond (Apple and Kikuchi 1975). Ancient Hawaiians would rake the pond floor to loosen and mix additional organic matter which had settled thus provides the fish with more food (Ualapu'e Molokai).

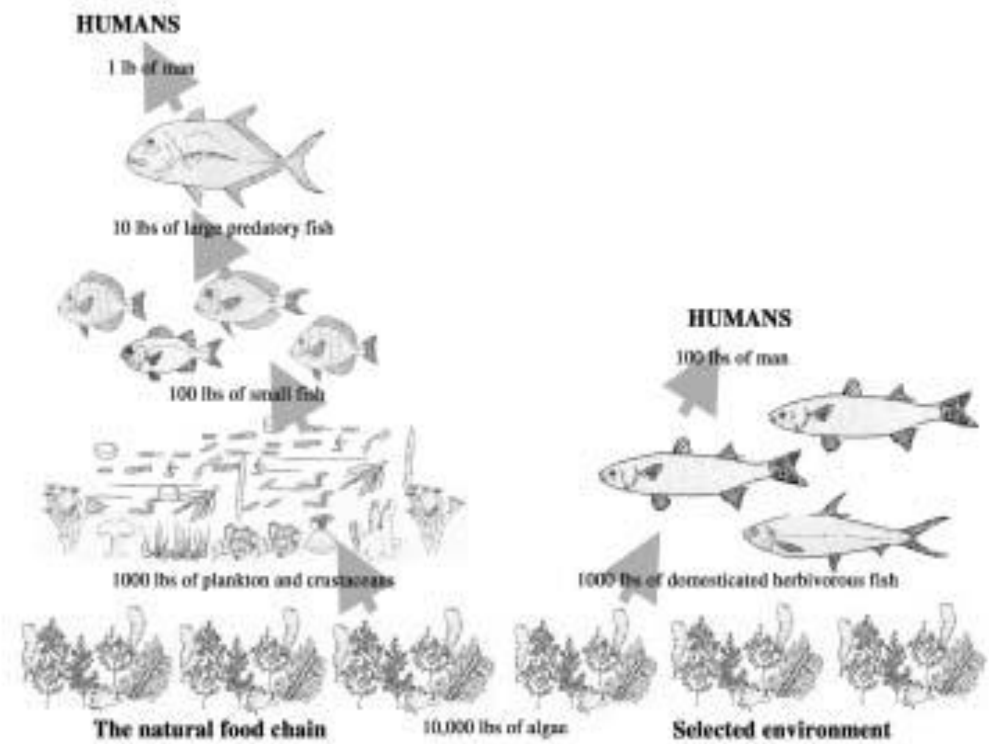

Figure 7 More herbivorous fish can be farmed with less impact then carnivorous fish. From Kikiloi 2003

Another external input used by modern fish farms is medicine (Costello et al. 2001). Fish in a densely populated area are subject to disease. This is due to the crowding of the fish as well as the poor water quality from excess fecal matter, especially in carnivorous fish species. Also epidemics are possible due to the lack of predators whose role in the ecosystem is to eliminate sick and weak prey (Packer et al. 2003). Modern industrial aquaculture combats this with large amounts of antibiotics (Costello et al. 2001). Although these drugs do help to reduce mortality, putting large quantities of antibiotics in the ocean is detrimental to the wild ecosystem as well as to the consumer as it promotes antibiotic resistance in human pathogens that occur naturally in the marine environment.

The Ancient Hawaiians relied on the natural ecosystem to combat pathogens, ectoparasites, and epidemics. These methods relied solely on the physical and biological properties of the fish pond. One of the best ways to eliminate the spread of disease is by predators (Packer et al. 2003). Ancient Hawaiian fish ponds had kaku or barracuda which were full time residents in the fish ponds (Apple and Kikuchi 1975). Predators prefer catching weak and sick fish thus reducing the spread of disease. Also fish ponds were usually located among sites of submarine groundwater discharge (Johnson et al. 2006), (Garrison et al 2003). This could possibly help reduce parasites due to changes in salinity.

Modern aquaculture requires major imports to function and they export most of their products. Kona Blue Water Farms sells 80 percent of their farmed raised kahala to upscale sushi restaurants outside of Hawaii (Chapter 190D State of Hawaii 2008). Although they are raising food, it is exported around the world. This does not provide food for the local community because of the high price. It would not be economically feasible for such a large business venture to provide food for Hawaii only; thus, they would not provide food security for the Hawaiian Islands.

Through the use of fish ponds, people in Hawaii could practice the Ahu'puaa method, providing their local community with locally raised foods. This would eliminate the use of fossil fuels via major transportation and also provide local jobs insuring that the community reaps the benefit of their ecosystem, the money made as well as the products grown.

There are hundreds of fish ponds in the Hawaiian Islands which now lie fallow (Kikuchi 1975). The infrastructure is there, but there are many issues when dealing with fish pond development and restoration (Hlawati 2002). Ownership issues are a major problem if one were to run a fish pond. Also, fish ponds are considered lands of historical importance; therefore, more issues arise when trying to develop an aquaculture operation. Legal issues scare most people away from developing fish ponds into aquaculture operations (Hlawati, 2002).

Although fish ponds were a symbol of wealth for the ruling class, production numbers were generally considered low at pre western contact times. With 1800s technology, fish ponds produced about 350 pounds of fish per year per acre, with a total of about 2.2 million pounds of fish per year for the state (Apple and Kikuchi 1975). With the aid of modern technology and the lack of tribal warfare, which specifically targeted fish ponds, much higher yields could be achieved while still being sustainable and environmentally friendly. . Presently the State of Hawaii consumes about 50 million pounds of seafood annually (State of Hawaii Department of Agriculture). Tribal warfare and the lack of modern technology lowered production rates, but ancient fish ponds could have produced almost 5 percent of modern Hawaii's consumer demand for seafood. Fish ponds are located on all the inhabited islands of Hawaii (figure 8) providing infrastructure for aquaculture.

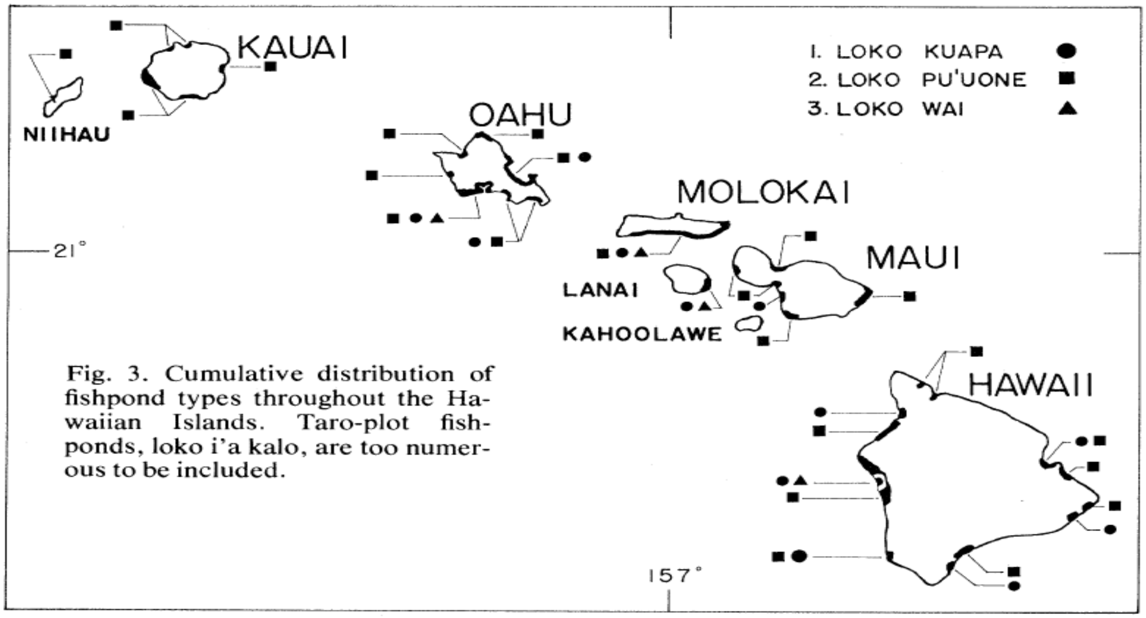

Figure 8 Fish Pond Distribution in Hawaii from Kikuchi 1975

Chapter 4 Conclusion

With the increases in population as well as rises in transportation cost, the demand for locally grown food will increase. Aquaculture has been a part of Hawaiian history since before European contact. With the advancements in aquaculture made possible by research since the 1970s, the State of Hawaii is becoming one of the country's leaders in aquaculture. Although this can potentially become one of the state's top income and food sources, it is still in the development stage; therefore, sites should be monitored constantly and permits allowed only after much scrutiny. The sea cage aquaculture industry is spreading in Hawaii and steps should be taken in order to have continued monitoring of these programs. Disease and nutrient loading should be monitored for an extended period in existing cages before more sea cage operations are allowed. Stocking density guidelines should be mandatory for all sea cage operations. Sea cage aquaculture operations have the potential to degrade the natural environment on which Hawaii's economy relies.

In the future when large scale transportation may not be economically feasible and major external inputs to aquaculture systems may not be readily available, modern aquaculture techniques might not be the best method for raising fish in Hawaii. Ancient Hawaiian technology minimizes the impacts on the environment as well as requiring little external inputs. This method could serve Hawaii in the future as a reliable, proven of aquaculture. The ecological principles which the Hawaiians developed over 600 hundreds years could be applied to modern aquaculture. Raising herbivorous fish, using predators as a form of disease control and relying on the naturally occurring feed would greatly benefit modern aquaculture and the Hawaiian Islands.

REFERENCES

AQUACULTURE Federal Management http://www.gulfcouncil.org/Beta/GMFMCWeb/Aquaculture/Economic%20Effects%20of%20Gulf%20Aquaculture%20Amendment.doc> (gulfcouncil.org)

Apple, Russell, Kikuchi, William (1975) Ancient Hawaii Shore Zone Fish ponds: An evaluation of Survivors for Historical Preservation, Office of the State Director National Park Service United States Department of the Interior. Honolulu, HI July

Beveridge , M.C.M (1996) *Cage Aquaculture, 2nd end*. Fishing News Books 346 pp.

Beveridge , M.C.M, Little, D.C. (2008) Aquaculture in traditional societies. In: Costa-Pierce B.A. *Ecological Aquaculutre* Blackwells, Oxford, pp.13-29

Boyra A, Sanchez-Jerez P, Tuya F, Espino F, Haroun R (2004) Attraction of wild coastal fishes to Atalntic subtropical cage fish farms, Gran Canaria, Canary Islands. Environmental Biology of Fishes 70(4): 393-401

Billig, Priscilla Offshore Aquaculture Project Yields a Traditional Hawaiian Delicacy, University of Hawaii Sea Grant College Program (NOAA NEWS) <http://www.oar.noaa.gov/spotlite/archive/spot_hawaii.html>

Costa- Pierce, **Barry** (1987) Aquaculture in Ancient Hawaii, BioScience, Vol 37 No.5 pg 320-330

Cleghorn et. Al (1990) Hawaiian Fish Pond Study Prepared by DHM INC., Bishop Museum Applied Research Group and Moon, O'connor, Tam and Yuen,

Costello M.J., A. Grant, I.M Davies, S. Cecchini, S. Papoutsoglou, D. Quigley and M. Saroglia (2001) The control of chemicals used in aquaculture in Europe, J. Appl. Ichthyol. 17 173-180

Corbin, John (1976) Aquaculture in Hawaii 1976 Prepared for the Department of Planning and Economical Development State of Hawaii.

Cross, T.F. G. Burnell, J. Coughlan, S. Culloty, E. Dillane, P. McGinnity, and E. Rogan (2008) Detrimental Genetic Effects of Interacxtions Between Reared Strains and Wild Populations of Marine and Anadromous Fish and Invertebrae Species. M. Holmer et al. *Aquaculture in the Ecosystem* Copyright Springer

Department of Agriculture and Department of Land and Natural Resources (2008) IMPLEMENTATION OF CHAPTER 190D, HAWAII REVISED STATUTES OCEAN AND SUBMERGED LANDS LEASING REPORT TO THE TWENTY-FOURTH LEGISLATURE STATE OF HAWAII 2008 REGULAR SESSION

Department of Agriculture Aquaculture Development Website, State of Hawaii www.hawaii.gov/hdoa/adp/faq05 accessed December 9, 2009

Farber, Joseph M.(1997) Ancient Hawaiian Fish ponds: Can restoration succeed in Moloka'i Neptune House Publications,Encinitas, CA..

Garrrison G.H., Glenn, C. R, McMurty,G.M.(2003) Measurement of Submarine Ground Water Discharge in Kahana Bay, Oahu, Hawaii, Limnology and Oceanography, Vol 48 No.2, pg.920-928

Handy, E.S. Craig and Hang, Elizabeth (1972) Nature Planters in Hawaii *Their Life Lore and Environment* Bishop Museum Press Honolulu Hawaii, 1972. (Handy et al. 1972)

Hawaii Aquaculture Advisory Council (1989). 1987 and 1988 Report, Department. of Land and Nautical Resources, May 1989.

Hlawati , Ian H. (2002). Loko I'a: A Legal Guide to the Restoration of Native Hawaiian Fish ponds Within the Western Paradigm , 24 University of Hawaii Law Review 657-692, 657

Hugenin, J.E., Ansuini F.J. (1978) A review of the technology and economics of marine fish cage systems. Aquaculture 15, 151-170

Johnson, Adam G. Craig, R. Glenn, William Burnett, Richard N. Peterson and Paul G. Lucey, (2008) Aerial infared imaging reveals large nutrient-rich groundwater inputs to the ocean. Geophysical Research Letters Vol.35 No. 15 August 16

Kona Blue Water Farms Website <http://www.kona-blue.com/sustainability.php>

Kikiloi, Kekuewa (2003). A new synthesis in oceanic domestication: The symbiotic development of *loko i'a* aquaculture in pre-contact Oceania SPC Traditional Marine Resource Management and Knowledge Information Bulletin #15

McGinnity, Philip Eleanor Jennings, Elvira deEyto, Norman Allott, Patrick Samuelsson, Gerard Pacific Business News Deep seawater helps aquaculture industry grow, Honolulu, Friday, September 26, 2008

Pacific Business News Hawaii aquaculture sales hit $25.3M in 2007 Pacific Business News, Honolulu, Monday, November 3, 2008. 2008)

Rogan, Ken Whelan and Tom Cross (2009) Impact of naturally spawning captive-bred Atlantic salmon on wild populations: depressed recruitment and increased risk of climate-mediated extinction *Proc. R. Soc. B* published online 29 July

Naylor, Rosamond L., Rebecca J. Goldburg, Jurgenne H. Primavera, Nils Kautskyk, Malcolm C. M. Beveridge, Jason ClayCarl Folke, Jane LubchencoI, Harold Mooney & Max Troell (2000) Effect of aquaculture on world fish supplies Nature vol. 405 29 June

Packer, Craig Robert D. Holt,Peter J. Hudson, Kevin D.Lafferty and Andrew P. Dobson (2003) Keeping the herds healthy and alert: implications of predator control for infectious disease Ecology Letters, 6: 797–802

Tacon , Albert G.J. Marc Metian (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects Aquaculture 285 146–158

Tamaru, Clyde S. and Christine Carlstorm-Trick (1998) Hawaiian Coastal Fish ponds, an Ancient System for Sustainable Aquaculture, Proceedings of the Aquaculture Resource Development in Pacific Islands: Cultural and Community Influences, Sustainability, Technology Applications and Commercial Opportunities, October 27-30, 1998 Tokai University, Honolulu HI.

The Natural Energy of Hawaii Authority/ Commercial Tenets <http://www.nelha.org/tenants/commercial.html> (NELHA)

Ualapu'e Moloka'i (1991) *Oral Histories from the East End* Center for Oral History Social Science Research Institute University of Hawaii at Manoa June 1991.

Whitmarsh D. , Palmieri M.G. (2008) Aquaculture in the Coastal Zone: Pressure, interactions and Externalities. M. Holmer et al. *Aquaculture in the Ecosystem* Copyright Springer